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Conformal Freeze-In & the Dark Photon

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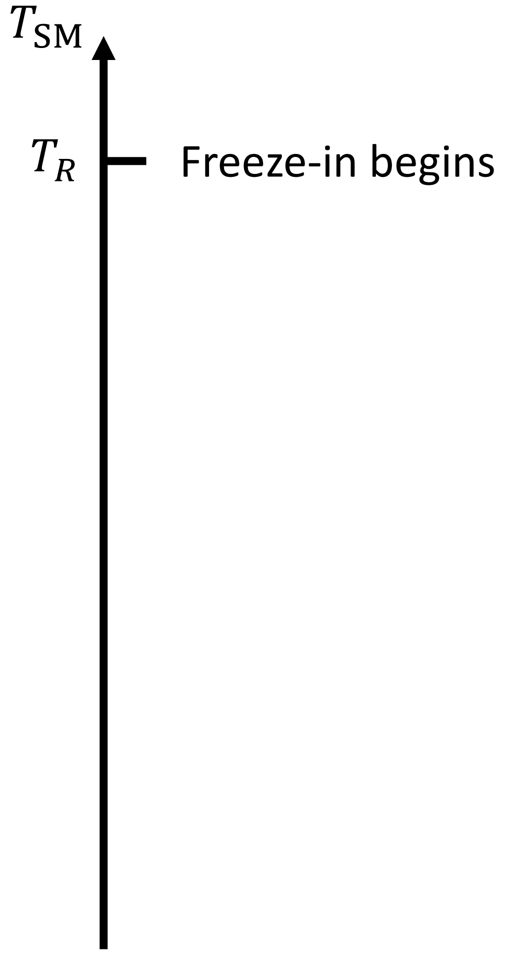
Based on arXiv:22XX.XXXXX

Motivations

- A model with:
  - Naturally small kinetic mixing
  - Asymmetric reheating
  - Naturally light, Higgsless dark photons (relative to v)
  - Potentially light dark matter
- Interesting thermal history

Cosmological Evolution



$$\mathcal{L} \supset \frac{\lambda}{\Lambda^{d-2}} B^{\mu\nu} \mathcal{O}_{\mu\nu}$$

$\lambda \sim 10^{-12}, d > 2$

Freeze-in processes:

$f\bar{f} \rightarrow \text{CFT state}$

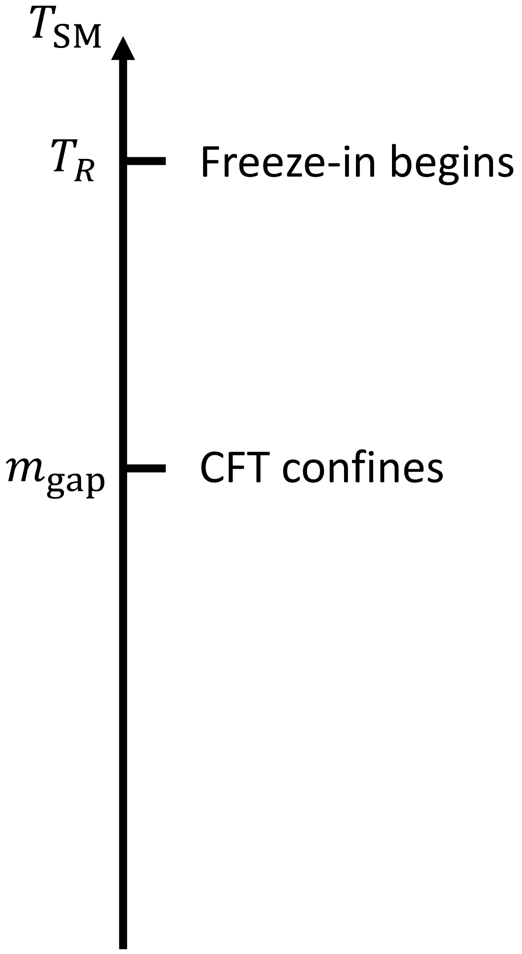
$A_\mu^* \rightarrow \text{CFT state}$

$$\rho_{\rm ds}(T_{\rm SM}) = \frac{B_d M_*}{\sqrt{g_*}(2d-5)} \left(T_{\rm SM}^{2\rm d-5} - T_R^{2d-5}\right) T_{\rm SM}^4$$

$$\begin{cases} d < 5/2 \Rightarrow \text{IR Freeze} - \text{in} \\ d > 5/2 \Rightarrow \text{UV Freeze} - \text{in} \end{cases}$$

$$\rho_{\rm ds}(T_{\rm ds}) = A T_{\rm ds}^4$$

Cosmological Evolution: Endpoint 1



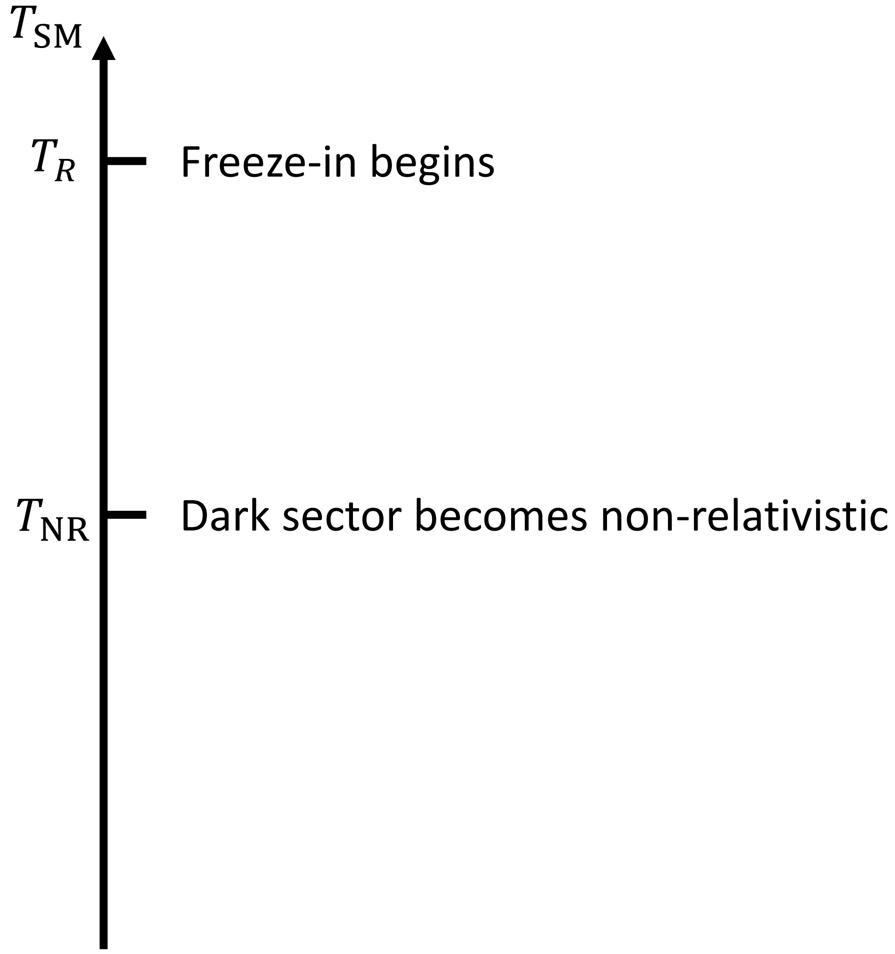
Dark sector particle spectrum:

Particle	Mass
ρ	$m_{\rm gap}$
π	$m_{\rm DM} = r m_{\rm gap}$

$$\mathcal{O}_{\mu\nu} \to \frac{1}{g_\star} m_{\rm gap}^{d-2} \rho_{\mu\nu}$$

$$\mathcal{L}_{\rm eff} \supset e \left(\frac{m_{\rm gap}}{\Lambda}\right)^{d-2} \frac{1}{m_{\rm gap}^2} \left(\bar{f}\gamma_\mu f\right)\left(i\pi^\dagger \overleftrightarrow{\partial}^\mu \pi\right)$$

Cosmological Evolution: Endpoint 2



$\rho_{\text{ds}}(T_{\text{SM}} = T_{\text{NR}}) = A m_{\text{DM}}^4$

↓

Modifies dispersion relation & Boltzmann equation

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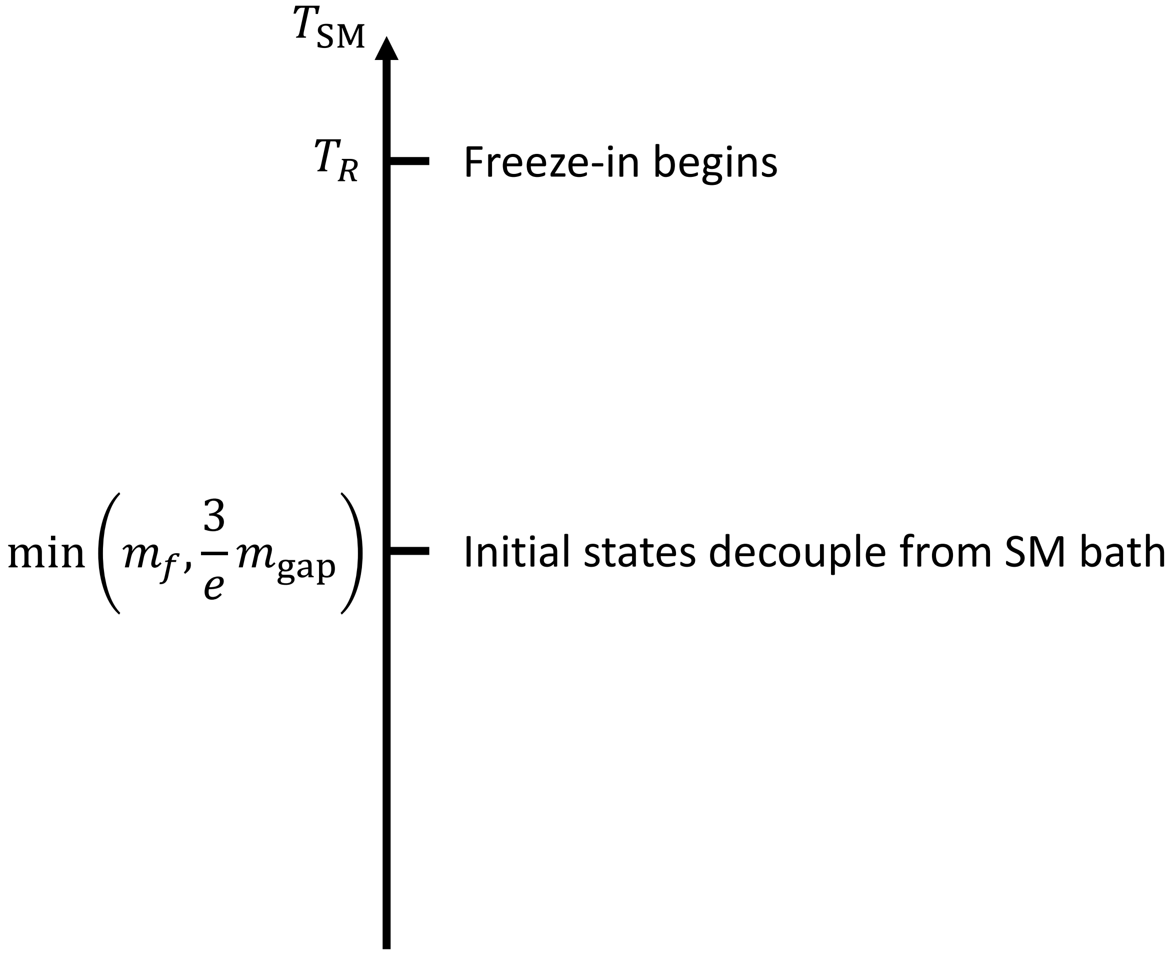
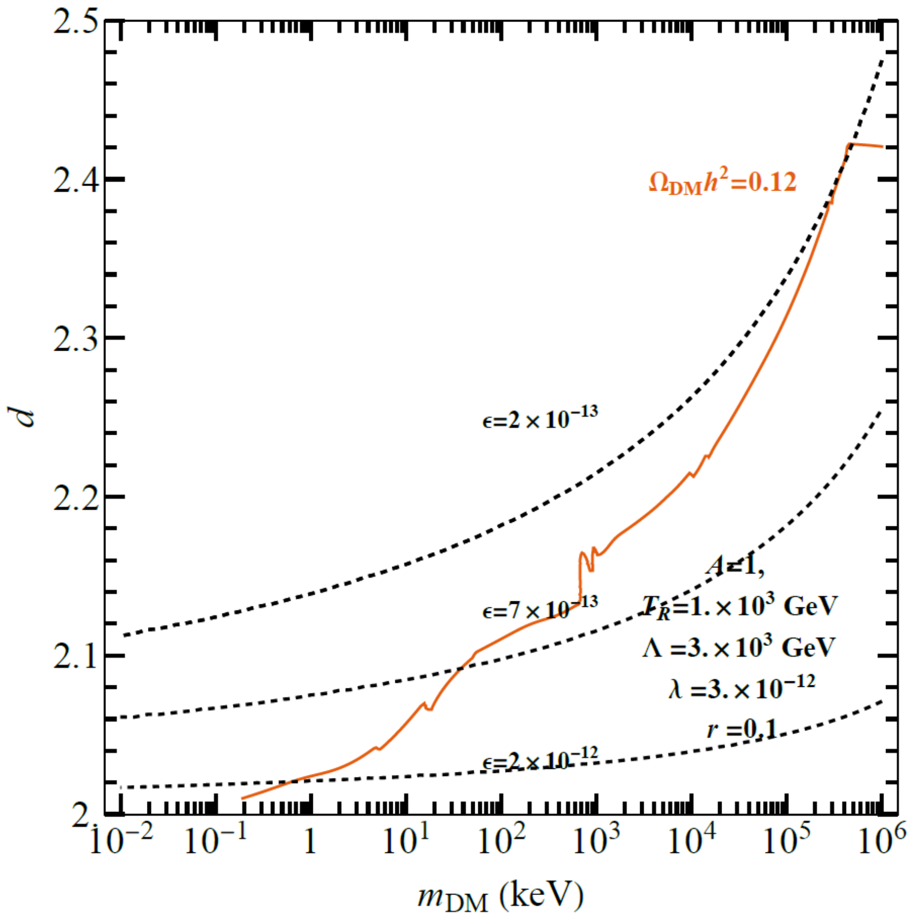
UV freeze-in $\forall d > 2$

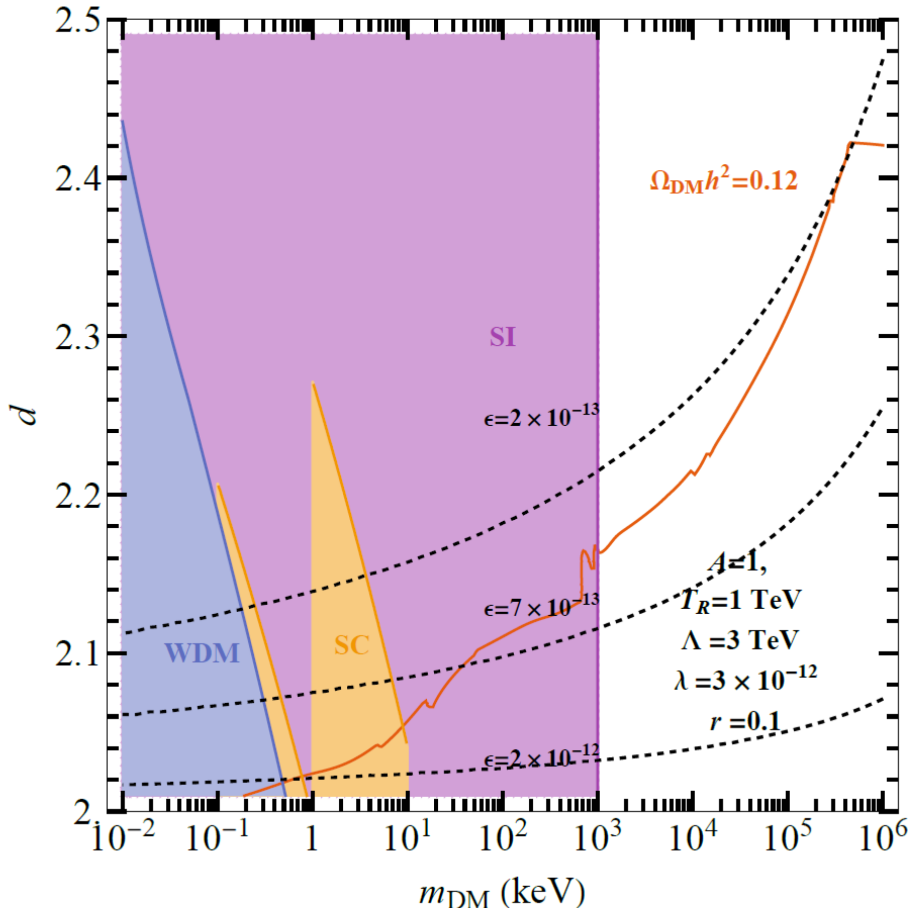
Cosmological Evolution: Endpoint 3



Relic density curves (IR freeze-in)



Constraints



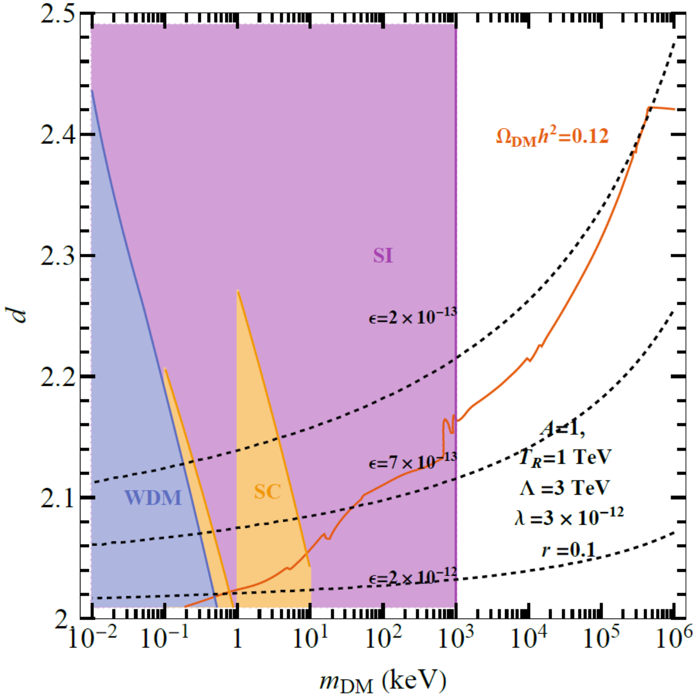
Self-interactions

- NDA yields

$$\sigma_{\rm self} \sim \frac{1}{8\pi}\frac{m_{\rm DM}^2}{m_{\rm gap}^4} = \frac{1}{8\pi}\frac{1}{m_{\rm gap}^2} r^2$$

- Imposing the galaxy cluster constraints, we get

$$m_{\rm DM} \gtrsim r^{4/3}\frac{100}{(36\pi)^{1/3}}\ \text{MeV}$$



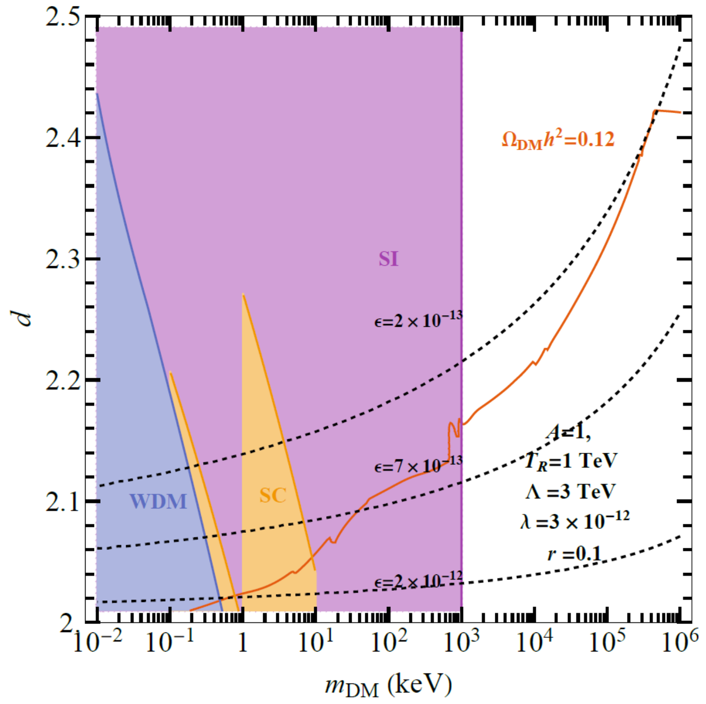
Warm dark matter bounds

- Relaxed by

$$T_{\text{ds}} \ll T_{\text{SM}}$$

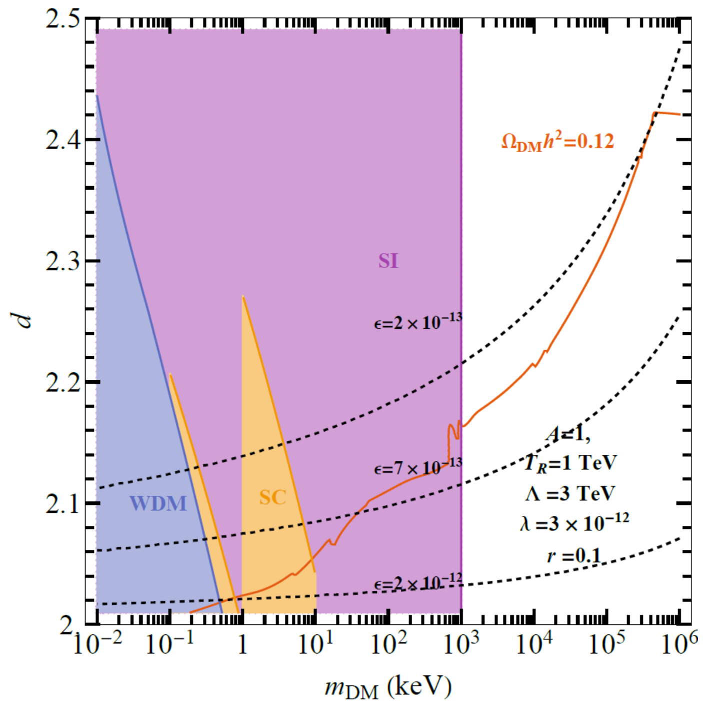
- Can be shown that

$$m \gtrsim m_{\text{bound}} \rightarrow T_{\text{NR}} \gtrsim m_{\text{bound}}$$



Star cooling bounds

- Different constraints for $T_{\text{star}} > m_{\text{gap}}$ vs $T_{\text{star}} < m_{\text{gap}}$
- Case with $T_{\text{star}} > m_{\text{gap}}$ places lower bound for d below 2
- Only has non-trivial constraints $rT_{\text{star}} < m_{\text{DM}}$

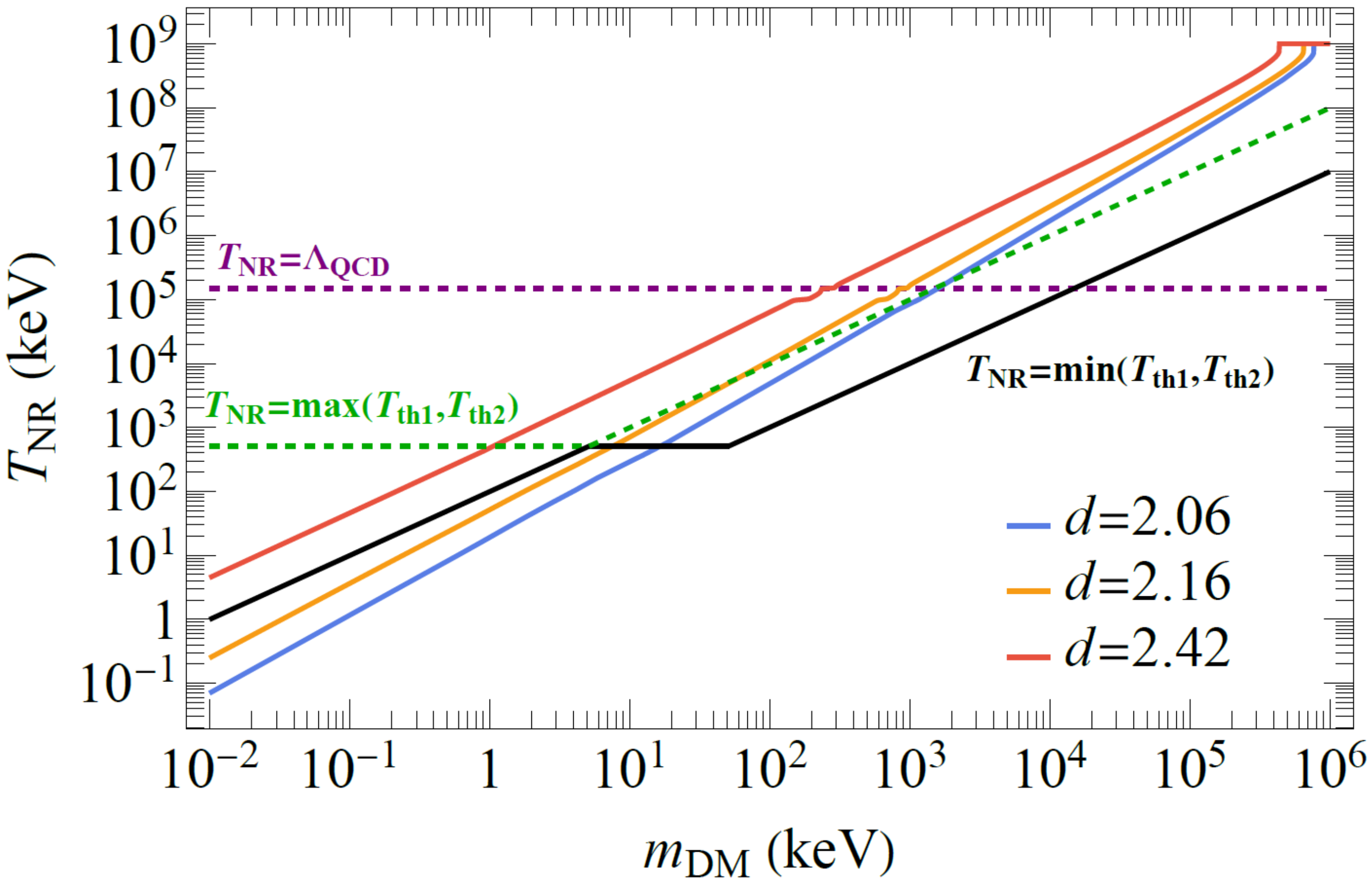


Conclusions

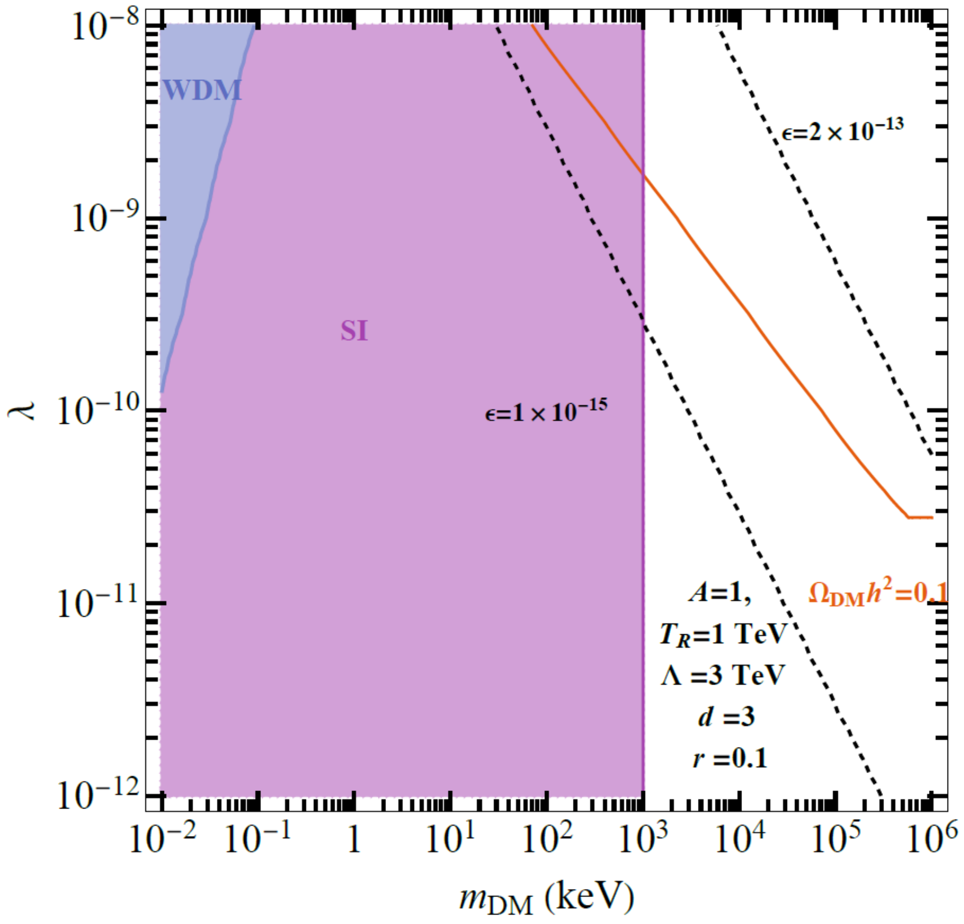
- A conformal phase for dark matter evolution is very interesting
- A large range of dark matter masses is allowed
- Strong self-interactions is a key observational constraint

Backup

T_{NR} curves



Relic density curve (UV freeze-in)



Small λ generation

- At scale $M \gg \Lambda$,

$$\mathcal{L} \supset \frac{\lambda_0}{M^{d_{\mathrm{BZ}}-2}} B_{\mu\nu} O^{\mu\nu}$$

- Strongly coupled theory runs (walks) to IR fixed point

$$\lambda \sim \lambda_0 \left(\frac{\Lambda}{M}\right)^{d_{\mathrm{BZ}}-2}$$

m_{gap} generation

- Needs local, relevant scalar deformation to CFT

$$\mathcal{L} \sim c_s \mathcal{O}_s \to m_{\text{gap}} \sim c_s^{1/(4-d_s)}$$

- Scalar deformation arises from $\mathcal{O}_{\mu\nu}\mathcal{O}^{\mu\nu}$ OPE
- Needs numerical CFT bootstrap

Asymmetric reheating